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ON THE COLD WATER MASS AROUND THE SOUTHEAST COAST OF KOREAN PENINSULA

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ABSTRACT

The cold water mass around the southeast coast of the Korean Peninsula is analyzed by using CSK data from 1966 through 1970.

It is shown that this water mass flows down from the region offshore of Jukbyun to the area of Youngil Bay along the 100 meter contour line of bottom topography. In ordinary summer conditions when the current velocity in the Korea Strait is usually above about 50 cm/sec and the wind direction is southwest, the cold water ascends to the surface and makes the surface temperature gradient large, unless disturbed by a tropical cylone.

The bottom water of the Korea Strait is formed by the stratification after the Tsushima Intermediate water and the Japan Sea intermediate water have been mixed. In winter the Tsushima intermediate water with high salinity sinks rapidly around the inlet of the Japan Sea and prevents the Japan Sea intermediate water from entering the Korea Strait.

INTRODUCTION

Variations of temperature, salinity, density, currents and winds over the cold water area that appears around the area off of Ulsan—the south east coast of Korea are investigated.

The presence of this cold water mass has often been noted in the existing studies of the Tsushima Current and the oceanic conditions of the Japan Sea at whose inlet the mass is found to be located. Among others, Lim & Chang(1969) and Yi (1970) analysed the data along the Ulgi-Kawajirimisaki and Pusan-Mitsushima sections and discussed in detail the occurrence and the boundary of the cold water mass. However, since its distribution and the route of motion extend over a broad area, the data from only two sections could not be considered sufficient for the synoptic description of the cold water mass.

The purpose of the study is to see: (i) how broad the cold water area is, (ii) where it is coming from, (iii) the relationship between its occurrence and the geostrophic current or the geostropic wind, and (iv) the possible relations with other water masses the North Korean cold water mass and the bottom water mass of the Korea Strait.

MATERIALS AND METHODS

The present analysis is based on the CSK data (Table 1) which were recorded from 1966 through 1970. Although the same CSK data from this area were analyzed in the past by Tanioka(1963) and Matsuyama (1973), their emphasis was not on the cold water mass, but on the current and the warm water mass.

Table 1. The period when the CSK data were taken.

1965	14 August—6 September; 2—12 December
1966	21 March—10 April; 14—28 July
1967	9—24 March; 12—25 August
1968	17 February—12 March; 1—22 August
1969	8 February—13 March; 9 August—6 September
1970	18—26 February 13—26 August

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Observations were made twice a year from 1965 through 1970 by ships of the Fisheries Research and Development Agency in Korea at approximately 60 stations inside latitudes of 34°40′N—38°12′N, and longitudes of 128°37′E —131°52′E (Fig.1). In spite of small differences in the positions of the stations from year to year, they can be considered the same points for the present analysis. The data in 1965 are excluded because they are incomplete.

In the analysis of atmospheric conditions around the area, the geostrophic wind perpendicular to the Pohang-Hamada line and the positions of the tropical cyclones approaching the Korea Strait are estimated from the weather charts published by the Japan Meteorological Agency.

RESULT

Currents and water masses

Seasonal variations of currents and water masses are not found in the CSK data which were only taken twice a year, although they were found in other data by Seki(1932), Tanioka(1968), Ogawa(1971) and others.

Tanioka(1968) showed that the Tsushima Warm Current passing through the west part of the Korea Strait is divided into three branches after entering the Japan Sea. The first branch continues to flow eastward and rejoins the main current of the Tsushima Warm Current off the coast of Honshu. The second strong branch, after being separated from the East Korean Warm Current off Jukbyun (37°N), turns to the south at 37°N. The third branch, the East Korean Warm Current, flows further north and its northernmost limit is presumed to be 39°N to 40°N. The location of the axis of this current fluctuates between the coastal area and considerably farther east off the Korean coast. The axis of the North Korean Cold Water seems to approach the coast of the Korean Peninsula in spring (March), gradually moves to the east in summer to autumn(October) and again comes back to the west in winter.

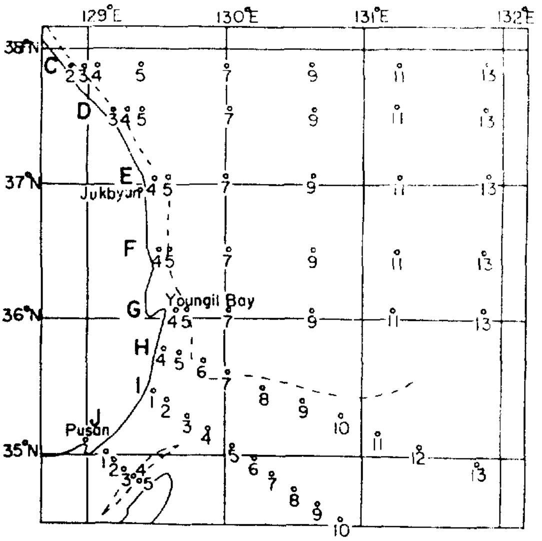

Fig. 1. Observation points. The dashed line indicates the 200 m contour line of bottom topography.

Ogawa (1971) noted that there is a remarkable similarity between the 100 meter subsurface isothermal diagram and the 50 decibar dynamical horizontal gradient (the reference level at 300 decibars). Fig. 2 shows the 100 meter subsurface isothermal diagrams in July 1966, August 1967 and August 1969. They have common features of dense isothermal fronts parallel to the coastal line and a long meridional narrow belt of cold water. Similar diagrams can be drawn using the data from other years.

Kajiura *et al.*(1958) suggested that the surface water temperature falls down due to the development of upwelling around the Jukbyun coast caused by the southward flowing current of the North Korean Cold Water in the west part of the Japan Sea.

In spite of annual or seasonal variations of the current, the existence of a permanent cold water mass is indicated about 30 meters below the surface. The mass roughly has the shape of a semicircle centered on Youngil Bay.

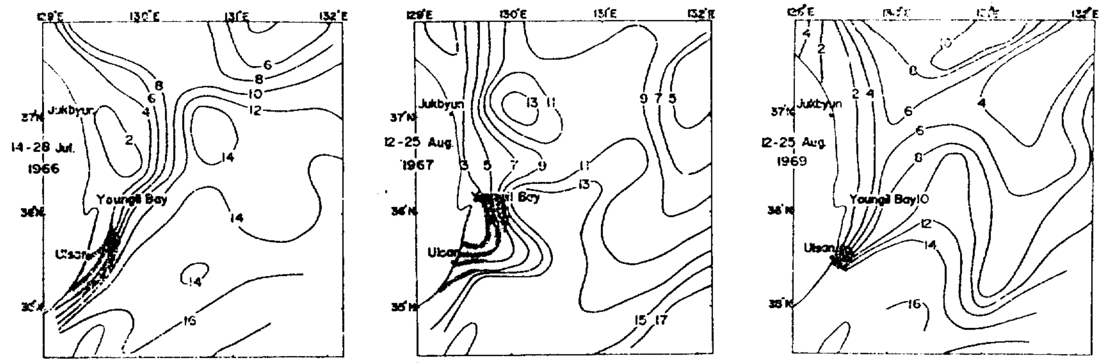

Fig. 2. The 100 m subsurface isothermal diagrams in July 1966, August 1967 and August 1969. The half dark regions indicate the surface cold water regions.

On the other hand, Matsuyama (1973) and Tanioka (1968) concluded that a clearly isolated warm water mass, centered at the point of 37°N and 131°E, is always present. The isothermal line digram for August 1967 in Fig. 2 is the same as shown by Matsuyama (1973). It shows that the Tsushima warm water mass has a tendency to sink after flowing into the Japan Sea. In summer the Tsushima warm water mixes with the Japan Sea Water and generally expands into a broad area, to a depth of 300-400 meters but in winter it forms a larger mass and sinks to a greater depth, as the water had a still higher salinity (34.7‰—35.0‰). For example, in March and April 1966, we can see a broad sinking area south of 37°N and the sinking can be traced down to the depth of 1,000 meters. The typical value of the temperature is 0.5—1.0°C and that of the salinity 34.5‰ at 400 meters below the surface.

Cold water mass

As mentioned above, the cold water mass around the region offshore of Ulsan, the southeast coast of the Korean Peninsula, is well known.

Lim & Chang (1968) remarked that the isothermal lines of the Ulgi-Kawajirimisaki section are always inclined upward on the western side (on the side of Ulgi) and downward on the eastern side (on the side of of Kawajirimisaki) and the inclination is mainly found in 18 miles from Ulgi and stretched southward to the area off of Pusan.

Fig. 3 shows the vertical isothermal sections of the I,H,G,F and E-lines in August 1967. In the I-section two thermoclines are seen, the upper thermocline (line A) and the lower one (line B), which ascends toward Ulsan. The upper thermocline appears only in summer whereas the lower one is present throughout the year. We may conclude that the former is the seasonal thermocline, and the latter, the permanent one. In the surface layer of section I1-I3 and H4-H7, the upper thermocline crosses the surface with a temperature gradient of 0.4°C/km. This feature is similar to the upwelling phenomenon observed off the Oregon coast by R. Smith (1968).

The tendency of this ascending towards the coast of the two thermoclines appears commonly in the G,H and I sections, but in the E and F sections the upper thermocline stays rather horizontal. In particular, the lower thermocline always tends to ascend in all sections up to 37°N in winter as well as in summer. In July 1966, in August 1967 and in August 1969 the surface temperature gradients have large values(Table. 2) due to the ascending of the upper thermocline, but in August 1968 the corresponding value is small because the

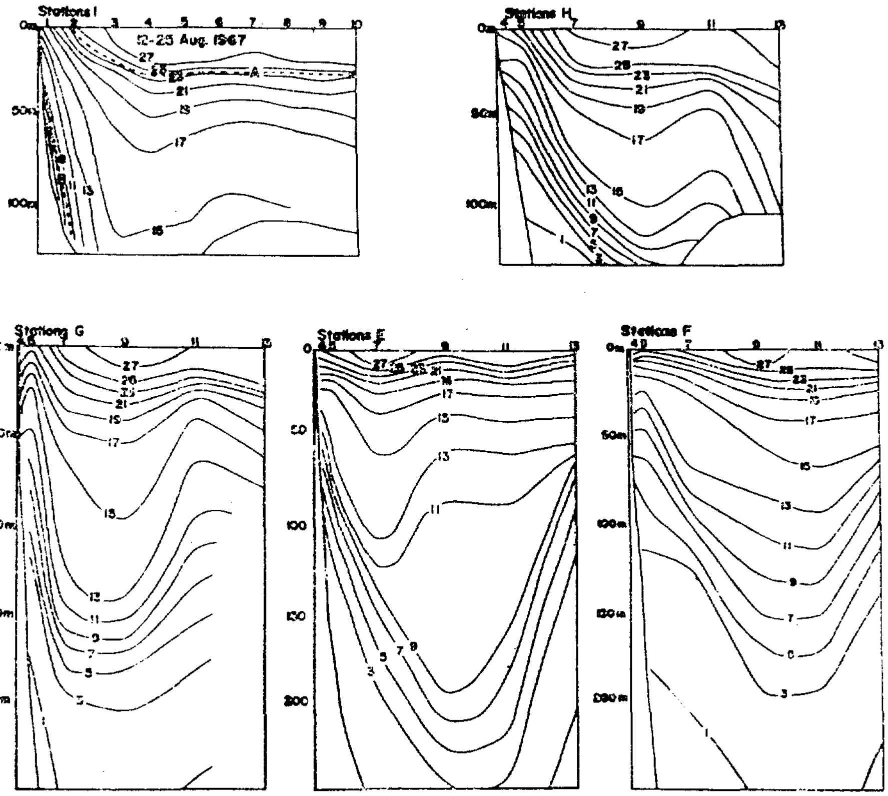

Fig. 3. The vertical isothermal sections of the I, H, G, F and E lines in August 1967.

thermocline does not cross the surface, it ascends only to 30 meters below the surface. In August 1970, the tendency of the ascent does not show at all. In winter the water mass in this area is almost homogeneous down to the bottom with T=15°C and S=34.0−34.7‰.

As described above, the cold water area is bounded by a semicircle from Pusan to Youngil Bay, with the maximum distance offshore being 30-45 km.

Here we must find the relationship between the three water masses, that is, the north Korean cold water coming down along the east, the cold water mass off Ulsan, and the Tsushima bottom water which is always present under the Korea Strait.

Fig. 4 shows the temperature-sality diagram for important points. The surface water of Korea Strait has a temperature of approximately 25-27°C. The low salinity below 30.0‰ in August 1970 should be attributed to rain fall before the observation. The observation points H5 represent the cold water region and, E5 and F5 represent the North Korean Cold Water. Although the surface water of Korea Strait (J4, J5, I3) is generally of high temperature and of low salinity, the water of the medium layer, below 50 meter depth, has a temperature of 15°C and salinity of 34.5‰. On the other hand the North Korean Cold Water has ranges of 0.5−4.0°C for the temperature and 34.0−34.05‰ for the salinity below 200 meters depth, as it approaches the proper water of the Japan Sea (Kajiura *et al.*, 1968).

We note some differences between the years. The T-S diagrams of H4 and I1 are similar to

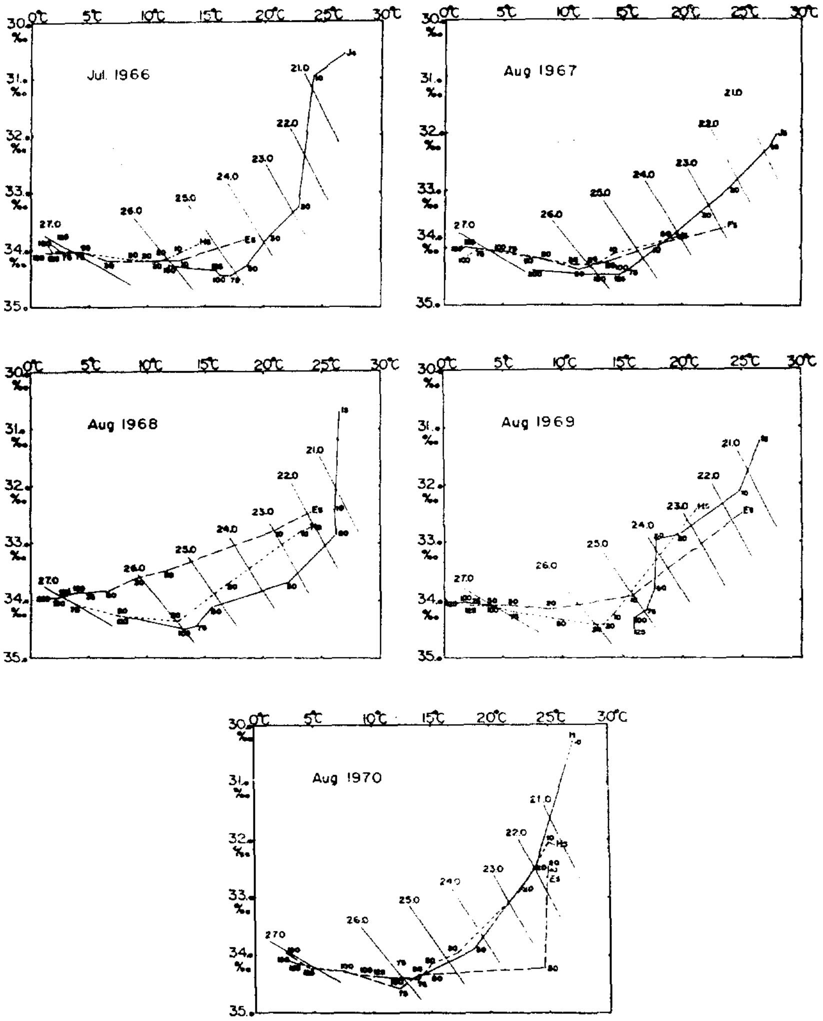

Fig. 4. The temperature-salinity diagrams for important points in summers of the five years.

those of the middle water of the North Korean Cold Water in July 1966, in August 1967, in August 1969. However those in August 1968 and in August 1970 have common features with the Tsushima Water. This suggests that the cold water mass offshore of Ulsan upwells from the middle layer of the North Korean Cold Water.

A possible route of motion of this cold water mass can be deduced by using the following procedure. Fig. 5 includes the horizontal T-S diagrams at depth of 10 m, 50 m, 100 m and 150 m during 14-28 July 1966. The figures and symbols on the diagrams represent the observation points. It is convenient to use this figure to see where the water of the heaviest density, namely the upwelled water mass, is found in each horizontal layer. As is shown in the T-S diagram (Fig. 4), H4 is the point of Water of the heavist density in the surface layer. In the 50 m layer the high density cold water centered at C3 and C4 stretches all over the region of the western part of the Japan Sea and flows down along the coast C4-G5. The Tsushima Warm

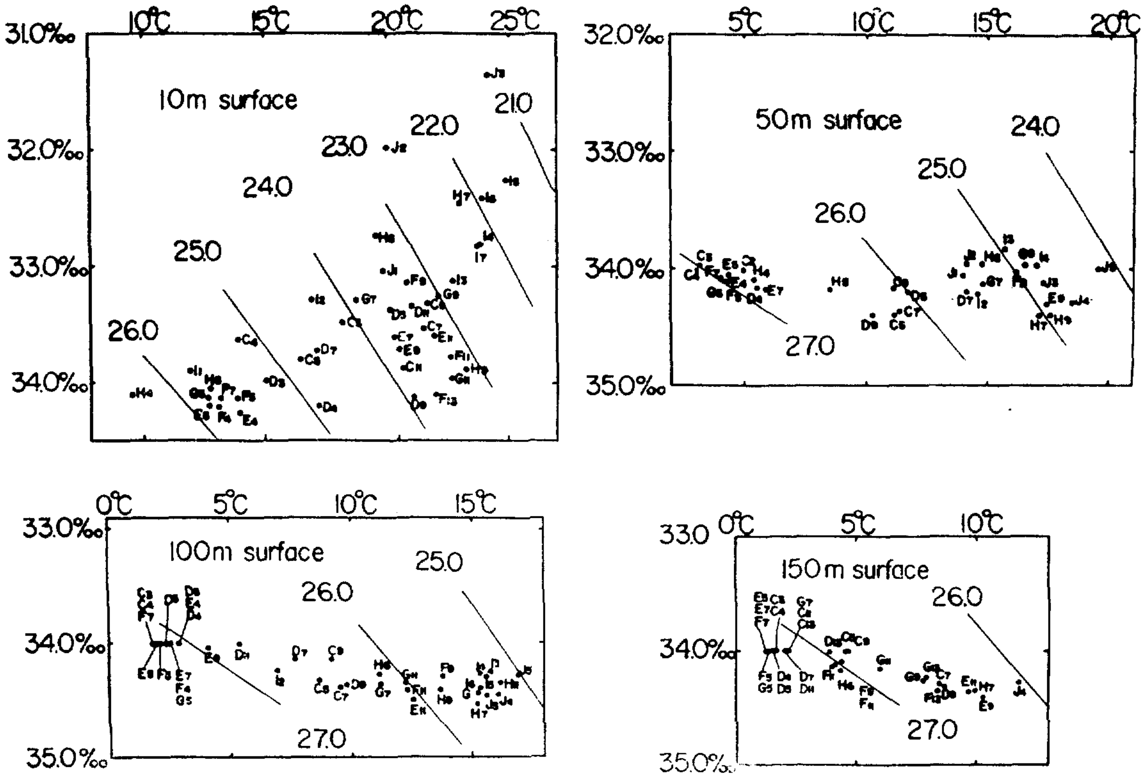

Fig. 5. The horizontal T-S diagrams at depth of 10 m, 50 m, 100 m and 150 m during 14-28 July 1966.

Water with a temperature of approximately 15°C and salinity of 34.1-34.4‰ is distinguished from the others. In the 100 m layer, the water at G5 already begins to show the characteristics of the proper water of the Japan Sea and is farther from that of the Tsushima Intermediate water (T=15-17°C). The fact that on the horizontal T-S diagram of 100 m layer the observation points are almost in a straight line between the Japan Sea Proper Water and the Tsushima Intermediate Water indicates the mixing process as in the case of the isentropic analysis. The water mass in G5 is not mixed with the Tsushima Water at all. The situation is almost the same in the 150 m layer. The result of the above analysis indicates that the North Korean Cold Water comes down from the region off of Jukbyun to the region off of Youngil Bay along the coast line, as if it were a meridional narrow belt below 100 m, and after reaching the area around Youngil Bay (H5) it comes straight up to the surface with little mixing.

Attention should be paid to J4 (T=11.7°C, S=34.27‰) in the T-S diagram of the 150 m layer. The temperature and the salinity in J5 on the T-S diagram in August 1967 are 7.5°C and 34.4‰. These values of J4 and J5 represent the Tsushima Bottom Water. Here it is worth mentioning the process of the formation of the Tsushima Bottom Water. According to Kajiura *et al.* (1968) the temperature and the salinity of the Tsushima Intermediate Water are 13-17°C, 34.2-34.7‰. In winter it has higher salinity than the above figure and comes from the East China Sea to the Japan Sea. At the entrance of the Japan Sea, the Tsushima high salinity intermediate water sinks along the slope of the bottom and prevents the Japan Sea

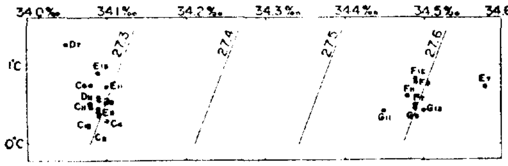

Fig. 6. The horizontal T-S diagram at depth of 400 m in spring 1966.

Water from approaching the strait, as is indicated by Fig.6. In summer the water mass formed by the mixing of the Japan Sea Proper Water and the Tsushima Intermediate Water is found on the sill of the Korea Strait. This becomes the Tsushima Bottom Water as it has a density intermediate between the other two water masses.

In the horizontal T-S diagram of the 100 m and 150 m layers in Fig. 5, those waters at the points G9, G11, G13, E7, E11, H7, etc. which are distributed in a straight line between the two water masses, are formed by the mixing process mentioned above. As for J4 and J5, the situation is similar.

The above discussions may lead to a conclusion that the cold water mass off Ulsan has different characteristics from those at other areas, having mixed only a little during its upwelling.

Relations with the geostrophic current and meteorological conditions

Although the quantitative relationship between the current and the wind could not be deduced because of the scarcity of observations of CSK data, it would be worthwhile to analyze the data of currents and winds in order to find a general tendency.

Fig. 7 shows the geostropic current in the summer season in the sections I2-I3, H5-H7 and G5-G7. But strictly speaking they must be described as vertical gradients of geostrophic current because the reference level is too shallow; the geostrophic current of I2-I3 refers to the 100 m depth level, H5-H7 to the 75 m depth layer and G5-G7 to the 125 m depth layer. But taking into consideration that the velocity of the southward current in the intermediate layer of the North Korean Cold Current is 20 cm/sec at its maximum(Kajiura *et al.*, 1958), it is a reasonable approximation to use them as the geostrophic current velocity. They agree with the value of velocity that was calculated in Ulgi-Kawajirimisaki using the 125 m reference level by Yi (1966). The maximum velocities in sections I, H and G are always located in I2-I3, H5-H7 and G5-G7 respectively. In 1966, 1967 and 1969, when the cold water mass was dispersed on the surface, the maximum velocities were greater than 50cm/sec(Fig. 7).

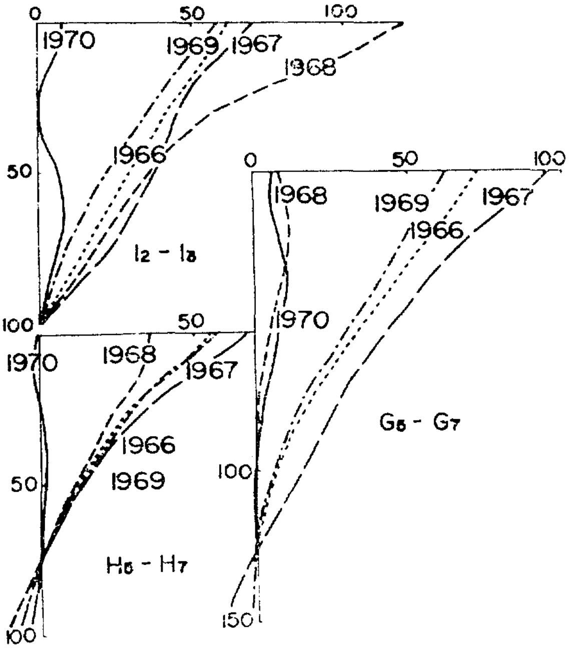

Fig. 7. The geostrophic current in the summer season in the sections I2-I3, H5-H7 and G5-G7.

Table 2 shows the surface temperature gradients at the 0, 30 and 50 meter levels around the cold water region in each year. Also in 1966, 1967 and 1969 the temperature gradient above 0.35°C/km is very great compared to that in 1968 and 1970. Generally it seems to

Table 2. The temperature gradient in the cold water region for sections I1-I3, H4-H7 and G5-G7 in summer during the five years (°C/km).

	I1-I3			H4-H7			G5-G7		
	0m	30m	50m	0m	30m	50m	0m	30m	50m
1966	0.35	0.35	0.40	0.28	0.27	0.27	0.05	0.37	0.38
1967	0.38	0.35	0.40	0.22	0.29	0.26	0.24	0.34	0.27
1968	0.09	0.25	0.14	0.02	0.10	0.09	−0.01	0.07	0.14
1969	0.30	0.16	0.36	0.07	0.19	0.28	0.15	0.24	0.40
1970	0.02	0.06	0.06	−0.01	0.04	0.03	0.00	0.00	0.12

be in proportion to the geostrophic current velocity of the axis of the Tsushima Current.

Geostrophic winds perpendicular to the Pohang-Hamada line are calculated. The results are given in Fig. 8. The weather data ten days ahead of the observations at H and I are used. It is seen that in 1966, 1967 and 1969, the southwest wind blew continously on those days and there was no atmospheric disturbance, whereas in 1968 the southwest wind blew continously and the tropical cyclone passed through the area three days before as in 1970. These results show that the occurrence of the cold water mass is more or less related to th geostrophic wind around that area.

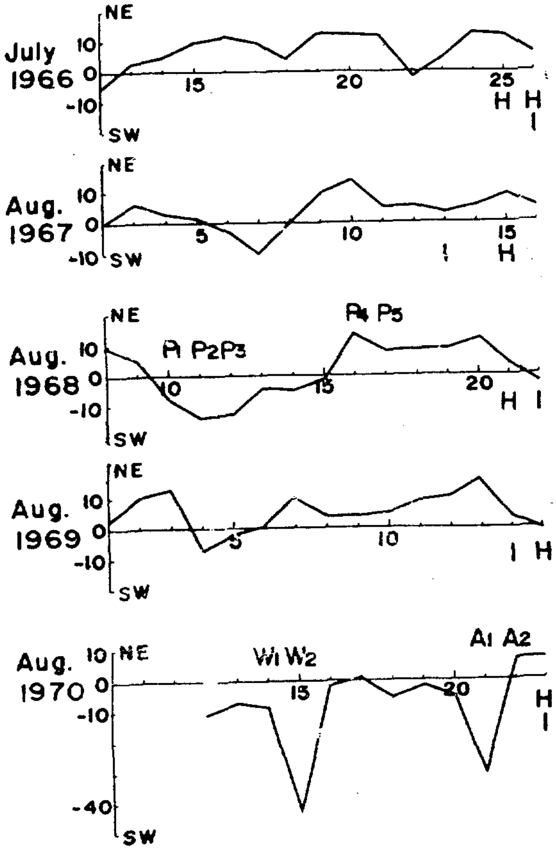

Fig. 8. The geostrophic winds (m/sec) perpendicular to Pohang-Hamada line in summer of the five years. The P1, P5, W1, W2, A1 and A2 indicate the date approaching the Korea Strait of tropical cyclones Polly, Wilda and Anita. Especially at P4 and A2 the tropical cyclones crossed the strait. H and I indicate the date when they were observed.

Conclusion

The cold water mass around the sout coast of the Korean Peninsula comes dow offshore of Jukbyun (37°N) to offs Youngil Bay along the east coast l meridional narrow belt and ascend surface around the region offshore of summer. There are times when the mass does not appear in the surfa that case the following three p simultaneously observed; (i) the Tsushima Current decreases, (cyclones cross the Korea Strai Sea and (iii) the wind dir northeasterly component. In water mass always upwells condition with a geostrop more than about 50 cm/s great northeasterly com

It remains to study other possible causes, but as for the relationships among the cold water mass, current and wind, the cold water phenomenon could possibly be considered as a coastal upwelling. More detailed and continuous data should be obtained in this area to understand the whole mechanism of the cold water mass.

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REFERENCES

Kajiura, K., M. Tsuchiya and K. Hidaka 1958. Report on the development of the Tsushima Warm Current, Fisheries Agency Reports, pp. 158-170, in Japanese.

Lim, D., and S. Chang 1969. On the cold water mass in the Korea Strait., Journ. Oceanogr. Soc. Korea, 4(2).

Matsuyama, M. 1973. The warm water region in the Japan Sea off the Korean Peninsula., Bull. Japan. Soc. Fish. Oceanogr..

Ogawa, Y. 1971. Report of the Yamaguchi Ken Sea Fisheries Research Station, in Japanese.

Seki, K. 1932. On the oceanic conditions in summer season offshore of the east coast of Korea., Umi to Sora, 12(2).

Smith, R. 1968. Upwelling., Oceanogr. Mar. Biol. Ann. Rev., pp. 11-46.

Tanioka, K. 1968. On the east Korean Warm Current(Tosen Warm Current)., Oceanogr. Mag. Japan, 20 (1).

Yi, S. 1966. Seasonal and secular variations of the water volume transport across the Korea Strait., Journ. Oceanogr. Soc. Korea., 1(1-2), 7-13.

Yi, S. 1970. Variations of Oceanic condition and mean sea level in the Korea Strait., The Kuroshio, 125-141.